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Measuring Vehicle Emission Loss Costs of Students of the Faculty of Economics and Business, Tadulako University with an Environmental Accounting Approach

Pengukuran Biaya Kerugian Emisi Kendaraan Bermotor pada Mahasiswa Fakultas Ekonomi dan Bisnis Universitas Tadulako dengan Pendekatan Akuntansi Lingkungan

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Abstract

Located in Palu City, Tadulako University is among the biggest emitters of pollution from heavy traffic. Particularly gasoline and diesel motor vehicles, transportation greatly adds to the higher emissions. This study intends to identify the elements influencing vehicle exhaust emissions and transportation activities, build a relationship model between them, compute the emissions amount, and project economic losses resulting from exhaust emissions at the Faculty of Economics and Business, Tadulako University. The results of multiple linear regression analysis on the calculation of emission load estimates and projected loss costs reveals that losses resulting from emissions at the Faculty of Economics and Business Tadulako University exceed IDR 18,668,454 annually.

Keywords: Emission Load, Environmental Accounting Approach, Exhaust Emissions, Student Transportation.

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Abstrak

Universitas Tadulako yang berlokasi di Kota Palu merupakan salah satu penyumbang emisi gas buang terbesar akibat tingginya aktivitas transportasi. Transportasi khususnya kendaraan bermotor berbahan bakar bensin dan solar memberikan kontribusi yang cukup besar terhadap peningkatan emisi. Penelitian ini bertujuan untuk membangun model hubungan antara emisi gas buang kendaraan bermotor dengan aktivitas transportasi, mengidentifikasi faktor-faktor yang mempengaruhinya, menghitung besarnya emisi, dan mengestimasi kerugian ekonomi akibat emisi gas buang di Fakultas Ekonomi dan Bisnis Universitas Tadulako. Hasil analisis regresi linier berganda tentang perhitungan beban emisi dan estimasi biaya kerugian menunjukkan bahwa di Fakultas Ekonomi dan Bisnis Universitas Tadulako, besaran kerugian akibat emisi mencapai IDR18.668.454 per tahun.

***Kata Kunci**: Beban Emisi, Pendekatan Akuntansi Lingkungan, Emisi Gas Buang, Transportasi Mahasiswa.*

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INTRODUCTION

Given their very wide effects on many spheres of life, environmental problems have grown to be a major worldwide concern particularly in recent years (SDGs, 2025). Apart from global climate change marked by rising average temperatures of the planet, environmental effects also include air pollution, damage of ecosystems, and lower quality of human living. Particularly from the transportation sector, greenhouse gas emissions and other pollutants originating from human activities constitute one of the main causes of environmental harm. Fossil fuel-powered motor vehicles are one of the main sources of greenhouse gas emissions, such as carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), and hydrocarbons (HC), which are produced from the combustion process of fossil fuels. Furthermore, what is produced by motor vehicles are fine particles that can harm the ecology and human health (Hansen & Mowen, 2007).

With the majority of Indonesia's national greenhouse gas emissions coming from private vehicles, the transportation sector accounts for more than 25 percent of total national emissions (WRI Indonesia, 2023). High reliance on fossil fuels, little use of ecologically efficient public transportation, and less than ideal legislation on car emissions limits the worsening of this problem. The number of motorized vehicles continues to grow, which ultimately worsens air pollution and affects public health and the environment (Table 1).

Data from the Ministry of Transportation of the Republic of Indonesia (2022) show that there are now more than 125 million motorized vehicles in Indonesia, with private automobiles and motorbikes contributing most of the total. Motorized vehicles are utilized by staff, professors, and students in the university setting including Tadulako University to assist with daily transportation. For instance, the usage of private vehicles like motorbikes and cars is very prevalent at the Faculty of Economics and Business. Significant exhaust emissions resulting from this phenomena might compromise not only the air quality in the campus area, but also the health of nearby inhabitants and the surroundings.

Public health is also seriously threatened by motor vehicle air pollution. Long-term exposure to air pollution produced by motor vehicles, including fine particulate matter (PM2.5) and harmful gases, can increase the risk of cardiovascular disease, chronic respiratory disease, and lung cancer, according to WHO's study (2020). Conversely, the environmental impacts of motor vehicle emissions also include ecosystem damage, loss of biodiversity, and higher environmental mitigation costs; which not directly assessed or ignored in decision-making, so they are sometimes overlooked (Satria, 2024). The main objective of this study is to investigate the causal elements and estimate the cost of environmental damage caused by exhaust emissions from motor vehicles operated by the students of Tadulako University. Furthermore, this study is planned to offer data-based recommendations to help create green campus policies, including encouraging the use of public transportation, managing environmentally friendly cars, and educating about the need for proper vehicle maintenance.

Tabel 1. Number of Vehicles by Type

Id Table	Description	Unit	Year	Value (IDR)
A.1.4.05	Motorcycle	Unit	2022	125,383,489,00
A.1.4.05	Passenger Car	Unit	2022	17,202,328,00
A.1.4.05	Freight Truck	Unit	2022	5,489,679,00
A.1.4.05	Bus	Unit	2022	240,067,00

Source: portaldata.dephub.go.id, 2022.

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With an environmental accounting approach, this study is expected to make a significant contribution to the scientific literature and support the environmental sustainability agenda at the campus and national levels. Campuses as educational institutions have great potential to become models for implementing green policies that support environmental sustainability. However, irony often occurs when campuses that should be centers of innovation and education actually become significant contributors to environmental problems due to transportation activities. At the Faculty of Economics and Business, Tadulako University, for example, the high level of student private vehicle use poses a major challenge in managing air quality in the campus environment. Therefore, it is important to conduct research that not only measures the level of exhaust emissions but also analyzes the environmental impact holistically and provides a monetary value for the losses incurred. This kind of research can provide a more comprehensive picture of the contribution of motor vehicle emissions to environmental damage as well as being the basis for formulating environmentally friendly campus policies.

LITERATURE REVIEW

Environmental accounting emerged as a methodical strategy for examining and measuring the impact of human activities on the environment. Burritt & Schaltegger (2010) claim that environmental accounting offers a framework for discovering environmental impacts, monetizing them, and providing relevant statistics for strategic planning with sustainability issues. This approach can be used in the transportation industry to project costs associated with motor vehicle exhaust emissions, including health costs associated with diseases caused by air pollution, costs of ecological damage, and costs of climate change mitigation measures.

Many studies have shown how several elements affect car emissions, i.e.: vehicle type, fuel type, age, maintenance schedule, and fuel economy. Sianipar (2018), for example, found that compared to carburetor systems, fuel injection systems provide lower CO, HC, and CO_2 emissions. The study also observed that while CO_2 emissions are less affected by engine age, CO and HC emissions typically increase with vehicle age. Further contributing to increased exhaust emissions are larger engine capacities and higher vehicle mileage. Rusdiani (2018) also underlines how poor vehicle maintenance can lead to incomplete combustion, resulting in more pollutants. By using certain spark plugs, such as Iridium (BKR6EIX), Nurdin (2020) showed that fuel economy can be improved by 1.31 percent compared to normal spark plugs, thereby reducing emissions.

Land, air, and sea transportation are three categories of transportation, namely the movement of people or goods from one place to another. Land transportation includes non-powered vehicles such as trains and motorized vehicles such as trains, motorcycles, and cars. Water transportation includes ships, boats, and rafts; air transportation includes airplanes. Motorized vehicles dominate metropolitan areas because of their efficiency and comfort. Law Number 22 of 2009 concerning Road Traffic and Transportation defines vehicles as a means of transportation, both motorized and non-motorized (BPK RI, 2009). Both passenger transportation and the movement of goods and personal mobility utilize motorized vehicles.

Measuring annual, monthly, or hourly vehicle volumes, that is, the number of cars passing a particular observation location during a given period, helps one evaluate traffic density. Calculating emission loads relies on these statistics because they are directly related to the number of cars that exacerbate air pollution. Emission load calculations take into account vehicle type, fuel type, and specific emission parameters for each pollutant. For example, using vehicle activity data and emission

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factors, the Intergovernmental Panel on Climate Change (IPCC) offers recommendations for estimating emissions.

Emissions from motor vehicles have serious impacts on public health and the surrounding environment. By-products of gasoline combustion in automobile engines include pollutants including carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), carbon dioxide (CO_2), sulfur oxides (SO_2), and particulate matter (PM10). Long-term exposure to these toxins can lead to environmental problems including biodiversity loss and ecosystem degradation as well as respiratory and cardiovascular diseases. The World Health Organization (WHO, 2020) claims that long-term exposure to motor vehicle air pollution increases the risk of chronic respiratory diseases, cardiovascular disorders, and lung cancer. By increasing the level of CO_2 in the atmosphere and thereby causing global warming, automobile emissions also contribute to climate change. Thus, efforts are needed to minimize threats to the environment, as in accordance with the objectives of this research.

METHOD

This study seeks to aggregate data and delineate motor vehicle emissions in the vicinity of the Faculty of Economics and Business, Tadulako University, employing a quantitative methodology with a descriptive framework. The quantitative method, as articulated by Sugiyono (2016), involves acquiring knowledge through the use of numerical data to evaluate information pertinent to the subject of enquiry. The subjects of this study were students from the Faculty of Economics and Business at Tadulako University who utilise motor vehicles, including both automobiles and motorcycles. Population defines as a set of items or persons with specific characteristics identified by researchers for the purpose of drawing conclusions (Sugiyono, 2016). The precise population number is undetermined due to constraints in early data collecting and the nascent nature of the research. Consequently, the determination of sample size employs a practical technique via quota sampling rather than use a formula like the Slovin formula.

The quota sampling approach was used as it enables researchers to ascertain the number of responses from each group with flexibility, without requiring knowledge of the actual population size. Quota sampling as a strategy that involves selecting a sample from a population with certain characteristics until the predetermined number (quota) is attained (Sugiyono, 2016). Quota sampling establishes the number of respondents for each category without incorporating random factors, based on the research's requirements and constraints (Nazir, 2011). This study employed quota sampling due to constraints in time, resources, and the exploratory character of the research.

The sample was extracted from four academic programmes at the Faculty of Economics and Business, that is Accounting, Management, Development Economics, and D4 Public Sector Accounting. The initial three study programmes (Accounting, Management, and Development Economics) each had 103 respondents, whereas the D4 Public Sector Accounting and D3 Marketing Management programmes included 101 respondents each. The overall sample size in this study was 410 individuals. In each study programme, the researcher categorised respondents according to the kind of vehicle utilised, specifically automobiles and motorbikes. Each study programme allocated three respondents to automobile users and the remaining 100 respondents to motorcycle users. The content of the D4 Public Sector Accounting and D3 Marketing Management programmes remained same, however the overall number of respondents decreased somewhat to 101 individuals.

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The allocation of 103 people per study program aims to ensure balance between programs, thereby increasing the representativeness and fairness of the data collected. This decision takes into account time efficiency, simplicity of data collection, and adequate data analysis capabilities. This study aims to distinguish between car and motorcycle users from the early stages of data collection, thus offering a comprehensive analysis of vehicle emission characteristics depending on the type of vehicle used by students.

This study was conducted using SPSS version 25 software which helps process survey data from 410 respondents of students from the Faculty of Economics and Business, Tadulako University. The data used include vehicle type, daily mileage, fuel consumption, vehicle age, type of gasoline used, frequency and type of vehicle maintenance. Hendrialdi *et al*. (2020) examined the effect of vehicle age, maintenance level, and fuel supply technology on motor vehicle exhaust emission levels using SPSS in the context of exhaust emission research.

Multiple linear regression analysis, which aims to determine the effect of several independent variables such as vehicle type, vehicle age, fuel type, fuel consumption, and maintenance patterns on the dependent variable, namely the level of exhaust emissions from students' motor vehicles, is a data analysis method applied in this study (Ghozali, 2018). Because this approach allows one dependent variable to statistically describe the simultaneous relationship between two or more independent variables, multiple linear regression was chosen.

Multiple linear regression is one of the statistical tools widely used in quantitative research to test the effect of more than one independent variable on the dependent variable (Sugiyono, 2016). The findings of this regression analysis help develop data-based policy recommendations aimed at reducing emissions in the campus environment and understanding the relationship between student car features and the resulting emission levels. Furthermore, this technique increases the validity of calculating emission loads and environmental losses based on an environmental accounting perspective.

RESULTS

The data collected for this study were obtained from distributing questionnaires aimed at motor vehicle users, both cars and motorcycles, using gasoline or diesel fuel. The questionnaires that were successfully collected included two surveys for pertamax-fueled cars, fourteen surveys for pertalite-fueled cars, forty-nine surveys for pertamax-fueled motorcycles, and 345 surveys for pertalite-fueled motorcycles. This questionnaire was intended to collect data on several elements that affect exhaust emissions, i.e.: vehicle age in years, user maintenance level, vehicle engine capacity in cc, and vehicle fuel consumption in liters per kilometer.

The use of multiple linear regression analysis in this study is not only to assess the strength of the relationship between each independent variable, but also to build a model that estimates vehicle exhaust emissions based on student transportation activity features. The model output is used to calculate the overall emission load and assess the economic losses caused by air pollution. In effect, although the predictive capacity of the regression model is limited, its application remains significant in advancing the main objective of this study, which is to assess the environmental impact of emissions at the Faculty of Economics and Business, Tadulako University.

In the initial section, data processing is carried out which produces a multiple linear regression model for forecasting motor vehicle exhaust emissions. The model obtained shows that the independent variables in the form of vehicle age and vehicle engine capacity have a negative effect

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on vehicle exhaust emission value, while vehicle maintenance is identified as having a positive effect on exhaust emissions. The results of the R-Square (R^2) value is 0.156, which means that only 15.6 percent of the variation in exhaust emissions can be explained by the three independent variables. In other words, this model has low predictive ability, because there are still 84.4 percent of variations in exhaust emissions that are influenced by other factors that are not included in this research model.

In addition, the Adjusted R^2 value of -0.055 indicates that after adjusting the number of independent variables used, this model becomes insignificant in explaining variations in motor vehicle exhaust emissions. A negative Adjusted R^2 value indicates that the addition of independent variables to the model does not provide an increase in the ability to predict motor vehicle exhaust emissions. This can be caused by several possibilities, such as multicollinearity between independent variables, insufficient sample size, or other factors that have a greater influence on motor vehicle exhaust emissions but are not included in this regression model (Ghozali, 2018).

Based on the results of a survey conducted on 410 students of the Faculty of Economics and Business, Tadulako University, it was found that the majority of students, namely 96 percent, prefer to use Pertalite and Pertamax fueled motorbikes as their main mode of transportation; meanwhile, the rest use private cars as a means of daily mobility. The high percentage of motorbike users reflects students' preference for two-wheeled vehicles which are generally more efficient in terms of fuel consumption, operational costs, and ease of maneuvering on busy highways. Other data is shown in Figure 1.

The average age of vehicles used by students, both motorbikes and private cars, is around 5-6 years. Although most vehicles are still relatively new, there are around 8.29 percent of respondents who use vehicles that are more than 10 years old. The existence of these old vehicles is one of the factors that can contribute to increasing levels of exhaust emissions, considering that old vehicles generally experience decreased fuel combustion efficiency and the potential for increased air pollution due to engines that are no longer optimal (Pryciński *et al*., 2025).

In addition to the age of the vehicle, the maintenance conditions carried out by students also showed a very significant difference. The survey results showed that only 65.37 percent of respondents routinely carried out vehicle maintenance, namely periodic oil changes, engine checks, air filter cleaning, and fuel system checks. This consistent maintenance aims to ensure the best engine performance and reduce vehicle exhaust emissions.

However, 34.46 percent of respondents rarely or never do car maintenance. This group mostly expressed the limitations of maintenance costs which are considered expensive, ignorance of the need for car maintenance, and minimal knowledge about the negative impacts of poorly maintained cars on the environment. Especially carbon monoxide (CO) and hydrocarbons (HC), vehicles that are rarely serviced often experience incomplete fuel combustion, which ultimately increases exhaust emissions (Rusdiani, 2018). The increasing levels of CO and HC in the air not only worsen the air quality around the campus, but can also have a negative impact on human health, especially for those who are regularly exposed to these contaminants over a long period of time.

Furthermore, higher exhaust emissions are caused by the use of low-quality gasoline. Some students prefer to pay less for fuel, without thinking about how it will affect the life of the vehicle's engine or combustion efficiency. Fuel that does not meet engine requirements can cause carbon residue accumulation, reduce engine power efficiency, and accelerate damage to vehicle components which ultimately increases the amount of pollutants emitted into the air (Efendi *et al*., 2019).

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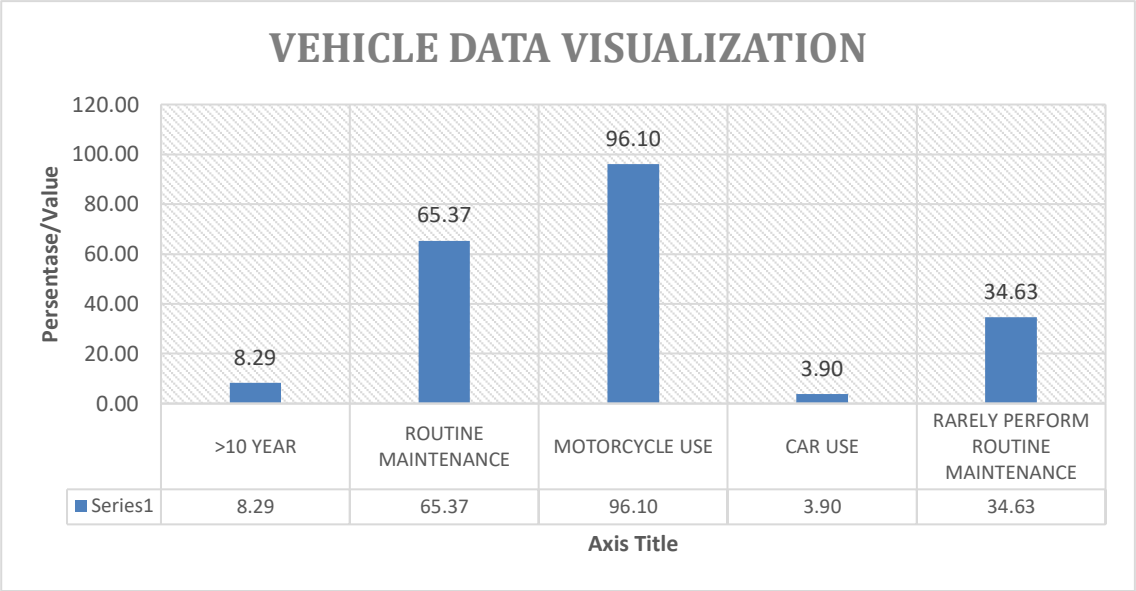


Figure 1. Vehicle Data Visualization
Source: Primary data (processed), 2025.

The findings of this survey help to better understand the car usage habits of the Faculty of Economics and Business, Tadulako University, students and the elements that cause exhaust emissions. More efforts are needed to educate students about the importance of proper vehicle maintenance, efficient fuel use, and the long-term impacts of exhaust emissions on the environment and public health as more motorized vehicles are present on campus. Further investigations can also be conducted to find mitigating solutions for the adverse effects of exhaust emissions, including the creation of a sustainable transportation system or the implementation of stricter environmental regulations in universities.

While private cars have an average fuel consumption of 1 liter for every 10–12 km traveled, motorcycle riders have an average fuel consumption of 1 liter for every 30–40 km traveled. Although the contribution of four-wheeled vehicle emissions remains greater due to increased fuel consumption per unit distance traveled, this shows that motorcycles are more fuel efficient than cars. Daily travel distances for students vary by location. Respondents living outside the city reported an average travel distance of 20–50 km per day, while respondents living in the city reported only 5–15 km per day. These travel patterns affect fuel use and emission levels. Students living far from campus have higher fuel consumption, which contributes to increased daily emissions.

Vehicle Exhaust Emissions

The research conducted at the Faculty of Economics and Business, Tadulako University also shows how big the contribution of student transportation activities, especially the use of two-wheeled motor vehicles, is to exhaust emissions, including carbon monoxide (CO), hydrocarbons (HC), and carbon dioxide (CO_2). The main cause of the increase in emissions in the university environment is the high dependence of students on private vehicles, which is reinforced by the intensity of daily use and the lack of understanding of proper vehicle maintenance.

Based on calculations using the IPCC standard emission factor of 2.36 kg CO_2 per liter of fuel, it is estimated that motorized vehicles used by students of the Faculty of Economics and Business, Tadulako University, contribute significantly to the total exhaust emissions in the campus environment. Specifically, the average exhaust emissions produced by motorcycles range from 2.36

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to 4.72 kg CO_2 per day, depending on the level of fuel consumption and engine efficiency of the vehicle. Meanwhile, private cars with larger engine capacities and higher fuel consumption produce much higher emissions, namely 11.8 to 23.6 kg CO_2 per day. If calculated on an annual scale, the total emissions produced by each type of vehicle reach 590 kg CO_2 per vehicle per year for motorcycles, and reach 2,950 kg CO_2 per vehicle per year for private cars.

This calculation shows that motor vehicles contribute more to the increase in carbon dioxide (CO_2) levels in the environment along with the increasing use of fuel. This result is in line with the empirical findings of Sidik (2023) which shows that the average total carbon emissions from motor vehicles in Banda Aceh City reached 95,800,861.76 tons of CO_2-eq/year, much higher than the emissions produced by electricity consumption which was only 460,053.3117 tons of CO_2-eq/year. This finding is in line with the results of this study, which proves that one of the main causes of the carbon footprint in the metropolitan environment is the transportation industry.

In addition to environmental impacts, exhaust emissions also cause economic and social losses (Efendi et al., 2019). These social costs are calculated based on an estimated social cost of carbon of $50 per ton of CO_2 or around IDR800,000 per ton of CO_2. Based on this assumption, the estimated annual social cost of carbon for each type of vehicle is as follows. For motorcycles it is IDR472,000 per vehicle per year, while for private cars it is IDR2,360,000 per vehicle per year. If calculated for all 410 vehicles surveyed, the total social cost of vehicle exhaust emissions in the campus environment reaches around IDR307 million per year. This cost includes the impact on public health, ecosystem damage, and environmental mitigation efforts that must be carried out. From this calculation, it can be concluded that the use of private vehicles, especially cars with high fuel consumption, has a greater economic impact than motorbikes. Therefore, it is important to consider emission reduction policies through the use of public transportation, electric-based vehicles, or policies to reduce the use of private vehicles in the campus environment.

The results of the study indicate the need for sustainable transportation policies in the campus environment. Some recommended steps in producing mitigation strategies and policies are as follows. The first step is to have environmental awareness and education in universities to help students realize how bad motor vehicle emissions are for the environment and human health. Regular educational campaigns or initiatives that explain the need for vehicle maintenance, the risks of air pollution, and personal efforts to reduce carbon footprints can help make this happen. Good education can inspire adjustments in vehicle use behavior towards more environmentally friendly behavior through efficiency.

Second, there must be encouragement to use environmentally friendly transportation on campus, to inspire students to use low-emission mobility options including alternative fuel cars, electric motorbikes or bicycles. The campus can offer supporting facilities such as electric vehicle charging stations, special parking spaces for environmentally friendly cars, or perhaps discounts on parking fees for green vehicle users as a kind of incentive. This stage seeks to reduce the dominance of fossil fuel vehicles on campus. The third effort is to limit the use of old vehicles. According to survey data, cars that are more than ten years old often have higher levels of pollution. Therefore, policies that limit or control the use of old cars on campus, for example by requiring regular emission testing or limiting access areas for old vehicles, are very necessary. Maintaining air quality in the university environment and reducing the potential risk of air pollution depend on this stage. The fourth effort is to improve campus green facilities and public transportation. Providing a fast and effective alternative to public transportation, including electric shuttle buses, is one long-term

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improvement that can be made. Furthermore, the construction of safe and enjoyable bike lanes can inspire students to switch to non-emission vehicles. Investing in green transportation not only helps the environment but also improves the comfort and health of university residents.

Vehicle Emission Load Analysis with Emission Factors

In this study, the analysis of the calculation of motor vehicle emission loads uses the emission load calculation method based on the Regulation of the Minister of State for the Environment No. 12 of 2010. Based on the data obtained, the calculation of motor vehicle emission loads is carried out based on emission factors from various vehicle categories. The calculation is carried out using the volume of vehicles obtained from the questionnaire, the average duration of travel within the city, and emission factors that correspond to the vehicle category.

After obtaining annual vehicle volume data, travel time data, and emission factors based on vehicle category, vehicle emission load calculations are carried out. The following is an example of calculating emission loads for CO type pollutants, where the data used are summarized in Table 2.

Tabel 2. Emission Load With Emission Factors

Vehicle Category	CO (g/km)	HC (g/km)	NOx (g/km)	CO2 (g/kg BBM)	CO2 (g/kg BBM)	SO2 (g/km)
Motorcycle	14	5,9	0,29	0,24	3180	0,008
Private Car	40	4	2	0,01	3180	0,026

Source: Secondary data (processed), 2025.

Calculation of CO Emission Load Gasoline-fueled cars (Pertamax and Pertalite):

COCars = Vehicle Volume x VKT x FE x $10^{(-6)}$
= (2 + 14) x 0.2193 x 40 x $10^{(-6)}$
= 0.00014 tons per year

Gasoline-fueled motorcycles (Pertamax and Pertalite):

COMc = Vehicle Volume x VKT x FE x $10^{(-6)}$
= (49 + 345) x 0.2193 x 14 x $10^{(-6)}$
= 0.00121 tons per year

The method for calculating the emission load of motor vehicles for other types of pollutants such as HC, NOx, PM10, and SO2 is almost the same as the calculation method for CO, only the emission factor (FE) of the pollutant is different according to applicable provisions.

Calculation of CO_2 Emission Load

The data used for the calculation includes the average fuel consumption of gasoline-powered cars in the city of 10 km/liter, the average fuel consumption of motorbikes in the city of 48 km/liter, and the specific gravity of gasoline of 0.76 kg/liter.

Gasoline-fueled cars (Pertamax and Pertalite):

BBMCar = 0.2193 / 10
= 0.02193 liters

BBMCarKg = 0.02193 x 0.76
= 0.01667 kg

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CO2Car = (2 + 14) x 0.01667 x 3180 x $10^{(-6)}$
= 0.00085 tons per year

Gasoline-fueled motorcycles (Pertamax and Pertalite):

BBMMc = 0.2193 / 48
= 0.00457 liters

BBMMcKg = 0.00457 x 0.76
= 0.00347 kg

CO2Mc = (49 + 345) x 0.00347 x 3180 x $10^{(-6)}$
= 0.00435 tons per year

Therefore, the scale of CO and CO_2 emission loads produced by cars in this study has been obtained and can be used as a basis for evaluating the impact of emissions on the environment in the studied area.

Analysis of Calculation of Loss Value Due to Vehicle Emission Load

Calculation of economic losses due to motor vehicle emissions depends on the pollution load produced by cars. The increasing number of cars can cause traffic congestion, which affects air pollution levels (Sasmita *et al*., 2022). Therefore, this study aims to assess the financial impact of vehicle emissions by estimating the cost per ton of emissions for each type of pollution produced in the environment of research object.

In this study, the technique suggested by the Victoria Transport Policy Institute (VTPI) was used to estimate the social cost of air pollution caused by motor vehicles (Litman, 2011). As an independent research organization, VTPI aims to create creative and relevant transport policies and strategies, especially regarding the calculation of the social and environmental impacts of motor vehicle emissions. The VTPI method offers a complete framework for measuring negative externalities of transport, namely environmental damage, impacts on public health, and financial costs paid. The following is the projected cost per ton for numerous forms of pollutants, i.e.:

- Carbon Monoxide (CO) = $205/ton
- Particulates (PM10) = $3.17/ton
- Carbon Dioxide (CO2) = $205/ton
- Sulfur Dioxide (SO2) = $1,000/ton
- Nitrogen Oxide (NOx) = $934/ton

Based on the March 2025 exchange rate of IDR16,356 per US dollar, the emission cost value in dollars per ton is converted into Rupiah in this study. The following is the projected cost of pollutants in Rupiah per ton:

- Carbon Monoxide (CO) = IDR3,352,980/ton
- Particulates (PM10) = IDR51,848.52/ton
- Nitrogen Oxide (NOx) = IDR15,276,504/ton
- Hydrocarbon (HC) = IDR719,664/ton
- Sulfur Dioxide (SO2) = IDR16,356,000/ton
- Carbon Dioxide (CO2) = IDR3,352,980/ton

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Tabel 3. Emission Load With Emission Factors

Pollutants	Car (IDR)	Motorcyle (IDR)
Carbon Monoxide (CO)	7,524	1,596,597
Particulates (PM10)	116	24,693
Nitrogen Oxide (NOx)	32,696	7,256,795
Hydrocarbons (HC)	1,543	341,829
Sulfur Dioxide (SO2)	34,476	7,768,065
Carbon Dioxide (CO2)	7,524	1,596,597
Total	83,878	18,584,576

Source: Primary data (processed), 2025.

Based on the loss value above, the amount of loss due to emission load at the Faculty of Economics and Business, Tadulako University can be calculated in Table 3. The calculation results show that the Faculty of Economics and Business, Tadulako University, experienced a total loss due to motor vehicle exhaust emissions of IDR18,668,654 per year. The loss caused by diesel-fueled vehicles was IDR83,878 and gasoline-fueled vehicles reached IDR18,504,576. These statistics show the financial impact of air pollution produced by motor vehicles in the area, thus helping to explain the poorer air quality and potential health hazards for surrounding residents.

Discusssion

The results of the study showed that most of the vehicles used by students of the Faculty of Economics and Business, Tadulako University were still relatively new with an age range of 5-6 years. However, as many as 8.29 percent of the vehicles used were more than 10 years old. According to Pryciński *et al*. (2025), older vehicles tend to have lower fuel combustion efficiency and less than optimal emission systems, which causes increased exhaust emissions such as carbon monoxide (CO) and hydrocarbons (HC). In addition to the age of the vehicle, the behavior of students in maintaining their vehicles also differs significantly. Around 34.46 percent of respondents stated that they almost never or almost never carry out routine maintenance including engine checks, air filter cleaning, and oil changes. Negligence in maintaining vehicles can result in incomplete fuel combustion, so that CO and HC emissions increase drastically (Rusdiani, 2018).

Third, fuel quality is an element that causes higher emissions. Some students decide to choose low-quality gasoline based on financial considerations. Setiawan & Prabowo (2019) claim that using gasoline that deviates from the vehicle engine specifications can cause carbon deposits to form in the combustion chamber and reduce combustion efficiency. This increases the volume of exhaust emissions and accelerates engine damage. In terms of fuel economy, motorcycle riders do show better results than vehicles. While vehicles only reach 10-12 km per liter, the typical consumption of motorcycle riders is 1 liter for a distance of 30 to 40 km. However, higher engine capacity and fuel economy help explain the larger proportion of car emissions.

This is in accordance with observations which show that, given the higher fuel consumption ratio per kilometer, vehicles remain the dominant source of emissions even though the number of motorcycles is greater. According to the calculation of CO_2 emissions, each motorcycle adds around 590 kg of CO_2 per year, while each car adds around 2,950 kg of CO_2 per year. The motor vehicle

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sector is the largest contributor to the carbon footprint in urban environments because this data is in accordance with the results in Banda Aceh City which shows that emissions from the transportation sector far exceed emissions from electricity use (Sidik, 2023). In addition to affecting the surrounding environment, vehicle emissions result in large financial and social costs. The annual social loss caused by emissions from 410 student cars reaches around IDR 307 million based on the social cost of carbon (SCC) methodology of $50 per ton of CO_2 or around IDR 800,000 per ton.

The government can reduce pollution levels by requiring emission testing for private vehicles, providing incentives for environmentally friendly vehicles, and building public transportation powered by renewable energy. Furthermore, one method to reduce the impact of air pollution is to establish low-emission zones and increase fees for cars that damage the environment. Effective implementation of these steps will improve air quality and improve public health. The use of gasoline with a higher RON value, such as Pertamax Turbo, can reduce vehicle exhaust emissions, especially HC and CO levels (Prasetiyo *et al*., 2022). The minimum HC level obtained in the test was 43 ppm, while the minimum CO level was 0.31 percent when using Pertamax Turbo at 8,000 rpm. This study underlines the need to use high-quality gasoline to reduce air pollution from motor vehicles.

Furthermore, a study conducted by Machmud *et al*. (2021) showed that vehicle age significantly affects the level of exhaust emissions. Their study revealed that about 29.05 percent of old vehicles (pre-2007) failed the emission test, which is based on a carbon monoxide threshold of 4.5 percent and a hydrocarbon limit of 1200 ppm. However, for new cars ($\geq$ 2007) with a carbon monoxide threshold of 1.5 percent and a hydrocarbon limit of 200 ppm, about 36.8 percent of vehicles failed to meet the criteria. These findings underscore the need for vehicle upgrades and stricter monitoring of automotive emissions. The findings of this study provide many avenues for further investigation. Initially, by using advanced statistical methodologies or machine learning algorithms, further research can create more precise predictive models, which allow for reliable assessment of vehicle emissions resulting from student transportation activities.

Second, to provide a more comprehensive analysis, further research should include other variables that may affect exhaust emissions, such as ambient temperature, driving behavior, and the nature of the travel routes used. This study could be expanded by comparing other faculties at Tadulako University with faculties at different educational institutions, so as to identify general trends and formulate broader policy recommendations. Fourth, a comprehensive examination of the impact of exhaust emissions on the health of students and the surrounding community could be conducted by distributing questionnaires on respiratory disorders or by physically assessing air quality. Finally, to reduce air pollution levels, further research could assess the efficacy of mitigation techniques used in the campus environment, such as limiting the use of vintage cars or promoting the adoption of electric vehicles.

CONCLUSION

With total losses exceeding IDR 18,668,454 per year, the study revealed that motor vehicle exhaust emissions result in significant economic and environmental costs. The largest is gasoline-powered cars, IDR 18,484,576; diesel-powered vehicles contribute IDR 83,878. This shows that the environment and health do suffer from motor vehicle air pollution emissions. The type of gasoline, the age of the car, and maintenance practices affect exhaust emissions. Older and poorly maintained cars often emit more emissions. Therefore, efforts are needed to reduce pollution through regular vehicle maintenance, the use of cleaner fuels, and the transition to electric cars.

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Although this study offers a fairly comprehensive picture of the contribution of student car exhaust emissions to economic and environmental losses, there are several limitations that must be considered for further research development. First, by using average fuel consumption statistics obtained from surveys and conventional emission factors, the method applied in this study is still an estimate. Because it ignores the actual condition of the car engine, this results in a fairly low level of accuracy in the results. Second, student self-surveys that are prone to perception bias such as errors in reporting vehicle age, fuel usage, or maintenance frequency are the main source of data. Third, this study has not included external factors such as vehicle speed, trip duration, and traffic conditions that can greatly affect emission volumes. Furthermore, the scope of the current study is limited to cars owned by faculty members of the Faculty of Economics and Business, so the findings cannot be generally applied to the entire university community or the people of Palu City.

While a critical component in determining the burden of air pollution on society, direct measurement of the health impacts of exposure to emissions was not allowed in this study. Environmental factors such as altitude, temperature, and wind direction that could influence the spread of contaminants across the university were also absent from this study. To obtain more accurate findings, more researchers are urged to apply direct emission measurement techniques using field emission measurements. Furthermore, involving the entire academic community into the study population and coordinating with local health data will help provide a more complete understanding of the impacts of automobile emissions on the environment and health. Future studies are also planned to assess the efficacy of the use of sustainable mobility options such as electric vehicles, bicycles, and regulations that limit private cars on campus.

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